Clinical Needs: Flow in Abdominal Disease & How We Image It

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The measurement of blood flow velocity using phase-contrast (PC) MRI was proposed by Moran in 1982, not long after Lauterbur's original description of NMR imaging (1). During the three decades following Moran's original proposal, flow velocity imaging methods using PC MRI have been developed and applied by many investigators (2,3). However, the broad clinical application of PC MRI has been somewhat limited in the routine clinical setting for a number of reasons including the difficulty in prescribing, acquiring, and post-processing the data. In addition, most data are typically acquired using 2D PC flow measurements which limit the diagnostic value to measuring blood flow velocity and rate over limited imaging volumes.

Recently, the application of imaging acceleration techniques have led to clinically practical methods to acquire cardiac gated, temporally and spatially resolved 3D PC flow measurements, and this method has been termed "4D Flow" MRI (4,5). Simultaneously, a variety of tools have been developed that facilitate qualitative and quantitative evaluation of 4D Flow data. These post-processing tools were originally developed for other engineering and manufacturing flow visualization applications, and have strong potential to contribute to our understanding of flow dynamics in vascular disease. The objective of this lecture is to review the 2D and 4D Flow acquisition and post-processing techniques in abdominal disease, and describe clinically practical approaches to measuring flow.

Qualitative Applications of 4D Flow techniques: Qualitative flow imaging with the 2D PC technique has a limited role in assessing abdominal disease. However, qualitative 4D flow imaging methods have significant merit, and leverage the ability to simulate actual flow speed and direction using visualization algorithms including flow streamlines, particle traces, cut planes, and tagging. These qualitative methods allow for reproduction of flow patterns similar to existing angiographic techniques as well as novel visualizations like virtual injections of inflow and outflow in a variety of vascular anomalies.

Quantitative Applications of 4D Flow techniques: 2D PC methods are the current most widely accepted method for measuring blood flow velocity and rate using MRI in the abdomen. The data are reliable as long as each site carefully corrects for deficiencies in the technique, including the impact of phase offset errors form eddy currents and other artifacts. 4D flow methods have shown promise to provide more accurate and precise measurements of blood flow velocity and total flow. The 4D techniques also allows the user to validate the accuracy and double check results using internal reference standards, like integrating flow in branch vessels compared to their arterial tributaries. In addition, advanced flow biomarkers provided by 4D Flow MRI have been shown to accurately reflect pressure gradients across lesions, pulse wave velocity, wall sheer stress, and heretofore unavailable non-invasive measures of biologic flow including helicity and energy dispersion. While our understanding of these biomarkers and their significance is only now emerging, quantitative 4D biomarkers will undoubtedly provide us with new measures of vascular flow in abdominal disease.

In summary, the emergence of practical 4D Flow MRI acquisition techniques have driven the development of novel visualization and rendering methods that are now moving the field into the "prime time" at specialized centers of MRI. The widespread dissemination of these techniques and application of the tools to abdominal disease will be contingent on development of streamlined tools for acquisition, visualization, and analysis of the methods in the community setting, a development that we can expect to witness in the next several years.

References: [1]Moran, Paul R. Magnetic Resonance Imaging 1.4 (1982): 197-203 [2] Firmin, D. N., et al. Magnetic Resonance in Medicine 14.2 (1990): 230-241 [3] Dumoulin, C. L., et al. Magnetic Resonance in Medicine 9.1 (1989): 139-149. [4] Markl, Michael, et al. Journal of Magnetic Resonance Imaging 17.4 (2003): 499-506. [5] Gu, Tianliang, et al. American Journal of Neuroradiology 26.4 (2005): 743-749.